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Assessing national renewable energy competitiveness of the G20: A revised Porter's Diamond Model

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ABSTRACT

To ensure energy security and tackle global challenges, such as climate change and environmental degradation, governments have formulated and implemented various public policies to encourage the development and utilization of renewable energy worldwide. This article focuses on potential approaches to evaluating and promoting the international competitiveness of Group 20's (the G20's) renewable energy industry. By developing a revised Diamond Model in relation to Porter's theory of industry competitive advantage, it provides an analytical framework for assessing the national renewable energy competitiveness of the G20 members, makes an in-depth investigation into the main driving factors for renewable energy industry, and presents a sound competitiveness assessment of the present and future of the G20's renewable energy industries, such as solar, wind, hydropower, and biomass energy. Based on the international analysis of the G20, the study also proposes a set of policy recommendations to support decision makers in the evaluation and choice of strategies for enhancing national renewable energy competitiveness. Our findings could better serve both policy makers and industrial end-users as a useful reference for international efforts to approach the sustainability of global energy use.

1. Introduction

Resource shortages (especially energy) and environmental problems have always been the major challenges for modern human society. With the rapid expansion of industrialization and urbanization around the world, many of these problems are getting worse. For instance, overexploitation of fossil fuels has led to climate change and environmental degradation, causing energy to be one of the most urgent and challenging public policy issues in the 21st century. To address this issue, the international community has made great efforts towards sustainable development by accelerating the transition to cleaner energy.

It is broadly believed that successful development of renewable energy could ensure energy security and mitigate climate change. Therefore, governments have been actively stimulating renewable energy growth on different scales. In the early 2000s, the European Union (EU) set a goal of transforming to a low carbon society. Moreover, the United States of America (USA) considers renewable energy as an important stimulator of domestic economic recovery. Meanwhile, emerging economies are catching up with developed countries in the global renewable energy race. China, for example, has promised that its carbon dioxide (CO_2) emissions will peak by 2030, when the percentage of non-fossil fuels in primary energy consumption will increase to around 20%.

The primary purpose of this article is to assess the renewable energy competitiveness of the world's major nations. By revising the Diamond Model proposed by Michael E. Porter [1], this study performs a quantitative analysis of the renewable energy industry competitiveness. It will uncover the driving forces of the renewable energy industry and provide a policy assessment framework for policy makers according to national resource endowments and competitive advantages.

Note that the so-called Group 20 (G20) in our paper is interpreted in a way that differs slightly from general perceptions. Data for the EU inevitably overlap with those for individual EU members, such as Germany and France, which are likely to adopt different key investment incentives to promote renewable energy, as will be explained below. Therefore, it may be reasonable to exclude the EU from the investigated list. Moreover, Denmark and Spain, which are member states of the EU but not of the generally perceived G20, have succeeded in structuring their renewable energy sectors. It is our conviction that lessons can be learned from those two countries. Therefore, countries in our analysis

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are the classic G20 members, excluding the EU, while including Denmark and Spain. Nevertheless, these will still be referred to as the G20 for reasons of simplicity.

2. Definition and literature review

2.1. Renewable energy

While there is no consensus on the definition of renewable energy, in general, renewable energy is defined as a suite of energy sources that: (1) are produced through ongoing natural processes, (2) can be naturally regenerated at a rate that equals or exceeds the consumption rate [2,3], and (3) can be continuously replenished [4,5].

People hold varying views on the sources of renewable energy, asserting that it comes 1) directly from the Sun (e.g., thermal, photochemical), 2) indirectly from the Sun (e.g., wind, hydropower), or 3) from other natural movement and environmental mechanisms (e.g., geothermal, tidal energy) [6]. Anyhow, one may conclude, from a broader point of view, that renewable energy is ultimately derived from the radiant energy of the Sun reaching the Earth [7]. Because of limitations in data availability, this study chooses to focus on four types of renewable energy: hydropower, wind, solar, and biomass.

Renewable energy has been widely recognized as a strategic direction for energy transition because of its sustainability and near-zero emissions. The International Energy Agency (IEA) predicts that renewable energy consumption will increase by an average of 2.6%/year between 2012 and 2040, while world net electricity generation will grow by merely 1.9%/year in the same period, and, because of this, the renewable share of world net electricity generation is estimated to expand from 22% in 2012 to 29% in 2040. More specifically, in 2012, the proportions of hydroelectricity, wind, and solar in total renewables generation were 77%, 11%, and 2.1%, respectively, and the other renewables (biomass, waste, tide/wave/ocean, etc.) accounted for approximately 8.5%; in 2040, these numbers would change to 52%, 23%, 9%, and 11.7%, respectively, [8]. During this period, hydroelectricity would still dominate the world's renewables, while solar would be the fastest-growing energy source, wind would hold a more important position, and biomass would mainly occupy the category of the rest of the renewables.

2.2. Competitiveness

The definition of "competitiveness" varies, depending on the scale, context and purpose of its use. It can be expressed in relative terms, referring to the comprehensive capacity reflected in the competition or comparison of two or more participants. Since the 1970s, competitiveness studies have been extensively conducted at multiple scales, ranging from nation, region, industry, and company to products. Reviewing the existing theories of competitiveness, one may divide them into three schools: 1) the Classical School; 2) the Neoclassical, Austrian, and Institutional School; and 3) the Contemporary School. There is a great variety of literature concerning the concept of competitiveness, most of the contributions rely primarily on the comparative advantage theory, which is ever-evolving, from the original absolute advantage and comparative advantage theory by Adam Smith and David Ricardo, to the theory of entrepreneurship and innovation by Joseph Schumpeter, to the management theory (the Diamond Model) by Michael Porter, and to the representative Paul Krugman's critical competitiveness theory—new economic geography theory [9]. For example, the World Economic Forum (WEF) defines international competitiveness as the ability of a country or a company to produce more wealth than its competitors under a world market equilibrium condition; thus, international competitiveness is deemed to be the unification of competitive assets and competitive procedure [10]. The Organization for Economic Cooperation and Development (OECD) shares the view that competitiveness represents, under favorable market conditions, the extent to which the country can produce goods and services for international competition, while synchronously capacitating the growth of real domestic income and living standards [11]. The International Institute for Management Development (IMD) argues that competitiveness is an effective means to achieve goals of improving living standards and enhancing social welfare [12].

Contrary to the general belief, neoclassical economists like Paul Krugman criticize the view that the concept of competitiveness is well-defined at the firm level, and it turns out to be “a meaningless word” if extended to the nation level [13]. Porter believes that the classical comparative advantage theory cannot adequately account for industrial competitiveness and that it is necessary to understand the concept with the aid of the competitive advantage theory. In his book, “The Competitive Advantage of Nations,” Porter defines industrial competitiveness as “Under the condition of international free trade, the capacity that a particular industry of a country provides more products that meet customers’ needs and reaps sustainable profits with its higher productivity” [1]. According to this definition, the ultimate source of national competitiveness is domestic industrial productivity. Porter's studies on industrial competitiveness provide a new paradigm that shifts the focus from comparative advantage to competitive advantage theory. Inspired by his book, a growing number of studies have underlined the importance of the competitiveness concept.

Computational structure of the so-called competitiveness-ranking index is the key to international comparison of competitiveness. To our knowledge, the Growth Competitiveness Index (GCI), by McArthur and Sachs [14], and the Business Competitiveness Index (BCI), by Porter, are probably two of the most classic competitiveness indexes. The former makes an evaluation based on factors that influence sustained economic growth over the medium-to-long term. The latter explores company-specific factors that generate improved efficiency and productivity indicators at the micro level as complementary to the GCI. In 2004, a new Global Competitiveness Index (GloCI) that takes advantage of both the GCI and BCI was created by WEF [15].

Given the complexity of the competitiveness concept, there would be great need for either multidimensional or composite indicators in assessing industrial competitiveness. This is the reason why many competitiveness index rankings make use of multiple indicators, such as the one proposed in the Global Competitiveness Report.

A literature review demonstrates that competitiveness may be defined in a variety of ways for different purposes. With respect to industrial competitiveness, it is necessary to understand the concept with the aid of the competitive advantage theory. Porter's book, The Competitive Advantage of Nations, has led to a shift of focus from individual firms and industries to a nation-wide scope, containing numerous firms and industries [16], thereby providing a new paradigm for international competitiveness analysis.

In addition, in recent years, “soft indexes” with no statistical standards have been increasingly employed in various international ranking systems, such as the Quality of the Judiciary, the Nation's Innovation Preference, the Extent of Corruption, and the Quality of Company Management [9].

2.3. Frameworks for assessing competitiveness of renewable energy

Porter's Diamond Model has now been widely applied to assess the competitiveness of one industry by investigating the mutual influences between elements (both internal and external components) and their influences on the whole industry. However, some researchers criticize the Diamond Model as lacking applicability in the nations that rely heavily not only on their multinationals but also in the activities taking place beyond national boundaries [16]. Following Porter, many researchers continue to revise the classical model in keeping with different end uses. Currently, there are three types of models in relation to the Diamond Model for assessing industrial competitiveness. These are the Porter-Dunning Model, the Porter Value Chain Model, and the Jin

Bei-Causal Model. Overall, most competitiveness studies are based on updated or refined versions of the Diamond Model, either by adding new contributing factors or adjusting parameters, rather than going beyond the analytical framework of the Diamond Model.

For example, Dunning introduced the concept of transnational corporations' commercial activities in his improved Potter–Dunning Model [17]. Rugman and Cruz explored the synergies of the Canadian Diamond Model and the American Diamond Model in their study of Canada's competitive advantage [18]. Cho developed a Nine Factors Model based on nine factors that can be classified into three categories: physical, human, and governmental [19]. Jin applied the Diamond Model to interpret China's market share and the profitability of domestic industrial products and proposed an economic analysis paradigm that fits well with specific conditions of Chinese industrial development. Based on this model, he set up an analytical framework for the international competitiveness of industrial products [20]. Rui added one key element—knowledge absorption and innovative ability—to the Diamond Model, with the argument that it is only with this core industry that sustainable competitiveness can be truly developed [21].

Renewable energy competitiveness research represents an important application in the domain of energy competitiveness research, in which the competitiveness denotes a country's international competitiveness in terms of renewable energy, such as wind, hydropower, photovoltaic (PV), and biomass energy, and associated industries. Relevant measurement indicators include renewable energy resource, investment, technological innovation index, the number of employees, total installed capacity, the Constant Market Share Model (CMS), Trade Competitiveness Index (TCI), and Revealed Comparative Advantage Index (RCA). Note that variations in indicators may exist among case studies for different purposes.

Certain index research systems have been put into practice. For example, the Global Cleantech Innovation Index (GCII) covers 40 countries, for which the score is calculated based on the average between inputs and outputs of innovation. Each of these inputs and outputs is determined by four equally weighted pillars: General Innovation Drivers (inputs), Cleantech-Specific Innovation Drivers (inputs), Evidence of Emerging Cleantech Innovation (outputs), and Evidence of Commercialized Cleantech Innovation (outputs). The four pillars comprise 15 indicators [22]. A similar example can be found in Ernst & Young's Renewable Energy Country Attractiveness Index (RECAI) [23]. However, many of the existing index systems remain problematic, due either to the lack of well-grounded theoretical foundations or to failure to focus exclusively on the renewable energy industry.

Unlike the case in many other industries, the use of the Diamond Model in renewable energy industrial competitiveness remains largely uninvestigated, apart from a few studies. These include Dögl and Holtbrügge, who analyzed Germany's competitive advantage of renewable energy firms over India and China by taking governmental and cultural influences into account [24]. In another study, Panagiotis and Nikos investigated the competitive advantage of renewable energy enterprises of Greece [25].

Some researchers have paid more attention to the industrial competitiveness of specific types of renewables. For instance, Zhao revised Porter's Diamond Model for assessing China's wind power industry by defining Government as the fifth determinant, rather than as a secondary element, and incorporating technology into the model as an intermediate variable [26]. Based on the Diamond Model analysis, Zhao developed a gear model as a way of understanding the dynamic process of the development of the PV industry [27].

In addition to the Diamond Model, research frameworks and tools, such as Fixed Effects Vector Decomposition (FEVD) [28,29], Panel Corrected Standard Errors (PCSE) [30], Event History Analysis (EHA) [31], and Data Envelopment Analysis (DEA) [32], have been widely applied to assessing the growth factors and driving factors of renewable energy and policy choices. Zhang assessed the international competitiveness of China's wind turbine manufacturing industry using the Analytic Hierarchy Process (AHP) in comparison to enterprises in Denmark (Vestas), Spain (Nordex), USA (GE Wind), Germany (Gamesa), and India (Suzlon) [33]. Sovacool adopted interviews and data analysis to compare the renewable energy industry competitiveness of ten countries in the Asia-Pacific region through a combination of interviews and data analysis, recommending a set of valuable design principles, common elements, and best features [34].

It is argued that the above-mentioned references reveal several shortcomings in the quantitative assessment of global renewable energy competitiveness. First, most of the studies assessed the renewable energy for particular countries, especially developed countries. International comparison of major economies, such as the G20, remains largely unexplored. Second, various new quantitative methods and tools that have emerged lack either rigorous scientific underpinning or critical insights into the classic Diamond Model. Based on a review of the state of the art in industrial competitiveness theories and practices, the remainder of this paper aims to address these issues by means of a revised Diamond Model for assessing the G20's renewable energy competitiveness.

3. Framework for assessing renewable energy based on a revised Diamond Model

3.1. Revision to the Diamond Model

The Diamond Model is chosen to yield our analytical framework from a new perspective. According to Potter's "Competitive Advantage: Creating and Sustaining Superior Performance," the idea of the value chain is based on the process view of organizations, the idea of seeing a manufacturing (or service) organization as a system made up of subsystems, each with inputs, transformation processes, and outputs. And, in the Potter's Diamond Model, the industry competitive advantage of a nation lies in four broad attributes: Factor conditions; Demand conditions; Related and supporting industries; and Firm strategy, structure, and rivalry [1]. Because this paper cannot give full consideration to the characteristics of renewable energy industries, the remainder of the paper will first establish a revised version of the Diamond Model.

3.1.1. Functioning of basic factors

According to the Diamond Model, basic factors that play a central role in modeling include natural resources, climate, location, unskilled and semiskilled labor, and debt capital. However, the importance of basic factors has been undermined by either their diminished necessity or their widening availability. In the discourse of renewable energy, some factors cannot be ignored and are thus deemed "basic." First, renewable energy resources are basically determined by geographical locations and natural endowments, which are of high spatial and temporal heterogeneity. Second, because of the long return on investment of renewable energy, capital plays a significant role in the renewable energy industries. As a result, the involvement of governmental investment is important for the emerging industry. Finally, the size of the labor force reflects, to some extent, the scale of the renewable energy industry due to its labor-intensive characteristic. For instance, abundant human resources have helped China perform well on solar cells production. As such, resource endowment, capital investment and labor force have been selected as basic factors for describing production conditions in this study.

3.1.2. Characteristics of "non-open international competition"

The Diamond Model focuses on industries and segments in open international competition. The functional significance of the renewable energy industry in mitigating global climate change, preventing environmental pollution, and ensuring energy security is much greater than is its commercial significance. Many countries have been finding ways to encourage the renewable energy industry. Incentive policies are adopted by governments to stimulate renewable energy growth.

Therefore, the Diamond Model needs certain revisions with respect to "open international competition." Some factors, such as environmental pressure (e.g., carbon emissions, particulate matter, and other atmospheric pollutants) and governments' policy incentives (e.g., renewable energy subsidies, mandatory quotas, and carbon tax) are playing a critical role and, thus, cannot be overlooked in the formation of a country's renewable energy competitiveness.

3.1.3. Definition of demand conditions

Demand conditions in the Diamond Model consist of several factors, including segment structure of demand, sophisticated and demanding buyers, anticipatory buyer needs, size of home demand, number of independent buyers, rate of growth of home demand, early home demand, early saturation, mobile or multinational local buyers, and influences on foreign needs. However, the system boundaries of some of the factors appear to be ambiguous and even to overlap with each other. Furthermore, some factors are hard to quantify due to data availability. For instance, segment structure of demand and sophisticated and demanding buyers cannot be properly quantified, while accurate data for anticipatory buyer needs, number of independent buyers, and influences on foreign needs cannot be obtained. Therefore, the existing sub-factors of demand conditions need to be refined. To that end, this study decomposes the demand conditions into four factors—market scale, substitution costs, environmental pressure, and policy incentive—with explicit definition and measurability, as will be illustrated below.

3.1.4. Internalization of "chance" and "government"

The roles of "chance" and "government" in the Diamond Model are also critical to industrial competitiveness. The impact of chance and government on renewable energy competitiveness is usually affected by factor conditions, demand conditions, related and supporting industries, and firm strategy, structure, and rivalry, etc. The influence of government lies mainly in the creation of chance to strengthen guidance and promotion of the aforementioned four key factors. For example, anticipatory buyer needs may arise as a result of a country's political or social values that will give rise to needs elsewhere. However, the Diamond Model still regards chance and government as independent factors, resulting in ambiguous boundaries between these factors. The unfairness of chance, for instance, is embodied implicitly in other factors and, therefore, is difficult to quantify at the national level. Government, which is always affected by factors like environmental pressure, is found to exert its influence on the renewable energy industry by implementing public policies, such as electricity quota obligation, financial subsidies, tax breaks, carbon trade, and carbon tax. As a result, in our analytical framework of renewable energy competitiveness, chance and government are incorporated into the four key factors, whereby the logical relationships between various factors and indicators are transparent.

3.2. Applying the revised Diamond Model to an analytical framework for renewable energy competitiveness

The Diamond Model has now been refined and revised to build an analytical framework of renewable energy competitiveness. The framework in our article contains an indicator system that brings together factors that both drive and hinder renewable energy development, as indicated in Table 1.

3.2.1. Factor conditions

Factor conditions refer to a nation's position in factors of production in the renewable energy industry, such as resource endowments, capital input, technology level, and skilled labor.

First, renewable energy resource endowments provide the basis for, and an important driving force of, renewable energy development. In general, the more abundant the renewable energy resources owned by a nation, the huger the development potential Second, capital investment is of vital significance to the renewable energy industry. Third, the technical level is also one of the key factors because advanced technologies may significantly increase productivity, decrease costs, and solve the energy storage problem. Finally, the labor force is, to a large extent, the source of national wealth, thus being indispensable in assessing the national renewable energy competitiveness.

3.2.2. Demand conditions

Market demand for renewable energy products or services generally includes four factors: market scale, substitution costs, environmental pressure, and policy incentive.

First, the market scale is obviously important to the renewable energy industry. Some studies have proved that, when market capacity doubles, product prices will drop by approximately 20% [35], suggesting that market demand will stimulate production. Second, in a fully-fledged market, any increase in the proportion of renewable energy would erode the market share of other energy. For consumers, price is an important factor in their decision-making. If the electricity price from thermal power is cheaper than that from renewable energy, apparently the substitution costs would be high. Consequently, fewer consumers would tend to choose renewable energy. In contrast, if the fossil energy price keeps rising, the effect of substitution would be more visible [36]. Third, renewable energy shows great promise in alleviating environmental pressure, which is jointly determined by the environmental capacity of a country and the environmental impacts associated with energy production and consumption. The larger the environmental capacity of a type of renewable energy than its environmental impacts, the stronger will be the environmental competitiveness of the renewable energy. Finally, the renewable energy industry is also dependent on public policies that influence the prospects for demand. Governments tend to stimulate corporate investment through policy instruments to speed up the commercialization of renewable energy technology. These policies will facilitate the transformation from fossil energy to renewable energy.

3.2.3. Related and supporting industries

Related and supporting industries mainly refer to industries closely related to the renewable energy industry, especially the upstream and downstream value chain. These include the manufacturing industry that provides components to the renewable energy industry and the electric power industry that benefits from the utilization of renewable energy. These related and supporting industries are likely to have a profound influence on the national competitiveness of the renewable energy industry. A superior industrial environment will boost renewable energy adoption by reducing expenses and increasing investment.

3.2.4. Firm strategy, structure, and rivalry

Firm strategy, structure, and rivalry refer mainly to the structure and management of domestic renewable energy firms, in addition to the performance of rivals. The more effective the renewable energy firm strategy, the more vigorous and competitive the industry. Likewise, the more open and intense the competition, the more efficient the resource allocation. Therefore, firms' strategy, management, and competitiveness play an irreplaceable role in the competitiveness of the renewable energy industry. First, wise policy is expected to encourage firms to launch renewable energy projects and improve their international competitiveness. Second, better enterprise competitiveness would help to reduce the cost of power-generation while improving product quality. Third, more technological advances would flow from additional competition, as firms act as the main stimulator of technical innovation and application.

Table 1
Theoretical framework for assessing renewable energy competitiveness based on the revised Diamond Model.

Theoretical factors	Definition	Supporting indicators
Factors conditions	Factors of production in renewable energy industry	Resource endowments, capital input, technology level, and skilled labor
Demand conditions	Market demand for renewable energy product or service	Market scale, substitution costs, environmental pressure, and policy incentive
Related and supporting industries	International competitiveness of supplier industries and related industries	Related industries that exert certain driving effects on the renewable energy industry
Firm strategy, structure, and rivalry	Structure and management of domestic renewable energy firms, as well as the performance of rivals	Firms' strategy, management, and competitiveness in the global market

4. Indicator system for assessing renewable energy competitiveness

4.1. Multi-criteria for the assessment

This study complies with the following criteria for assessing G20's renewable energy competitiveness.

4.1.1. Combination of theoretical framework and expert assessment

As indicated above, Porter's Diamond Model focuses primarily on the industries and segments that are capable of free competition in international trade, while stressing the national dimension of domestic demand and domestic suppliers. However, in practice, governments have extensively adopted policies of grant-in-aid, tax preferences, and special protection to support the renewable energy industry in the context of globalization. Thus, this article revises the Diamond Model to construct the assessment indicator system by regarding the world as a whole, while taking protectionism into consideration. In doing so, we incorporate experts' assessments (Fig. 1), which are acquired through seminars and questionnaires, into our theoretical framework.

4.1.2. Matching representativeness with availability

This study makes an effort to distinguish two levels of indicators that are representative and best available by making full use of international authoritative databases, including IEA, International Renewable Energy Agency (IRENA), World Bank (WB), and others. For example, the second level indicator for a nation's environmental pressure could be set with SO_2 emission reduction pressure, NO_x emission reduction pressure, $PM_{2.5}$ emission reduction pressure, CO_2 reduction pressure, etc. As mitigating global warming now receives top priority in global environmental governance, carbon deficit, which is defined as a measure of carbon footprint minus carbon emission allowance, has been selected as the indicator for environmental pressure.

4.1.3. Harmonizing multiple targets for energy, economy, and the environment

Governments may face dilemmas in promoting renewable energy. Germany, for instance, takes the lead in promoting incentive policies, such as a green pricing system for electricity; however, this may have undesirable consequences, such as market distortion and the rise of electricity prices. Therefore, it is our conviction that countries cannot make their development goals of renewable energy come true without a trade-off between not only economic development and environmental sustainability but also resource availability and energy security. Hence, this criterion has also been taken as a key basis for screening indicators.

4.1.4. Encouragement of competition and common development

Generally, the renewable energy industry of a country can stand firm in international competition only if it succeeds in domestic industrial competition. If a government provides fossil energy with high subsidies, as some countries with abundant petroleum resources (e.g., Saudi Arabia and Russia) do, the prospects of renewable energy do not seem to be promising. On the contrary, feed-in tariff policy has succeeded in helping countries to expand renewable energy. A desirable domestic environment for the renewable energy industry may trigger breakthroughs in the transition from fossil energy to renewable energy.

4.2. Description of the indicator system and data sources

Based on the above criteria, this article determines ten indicators of the indicator system. These are renewable energy resource, investment, cleantech innovation, employees, electricity installed capacity, gasoline

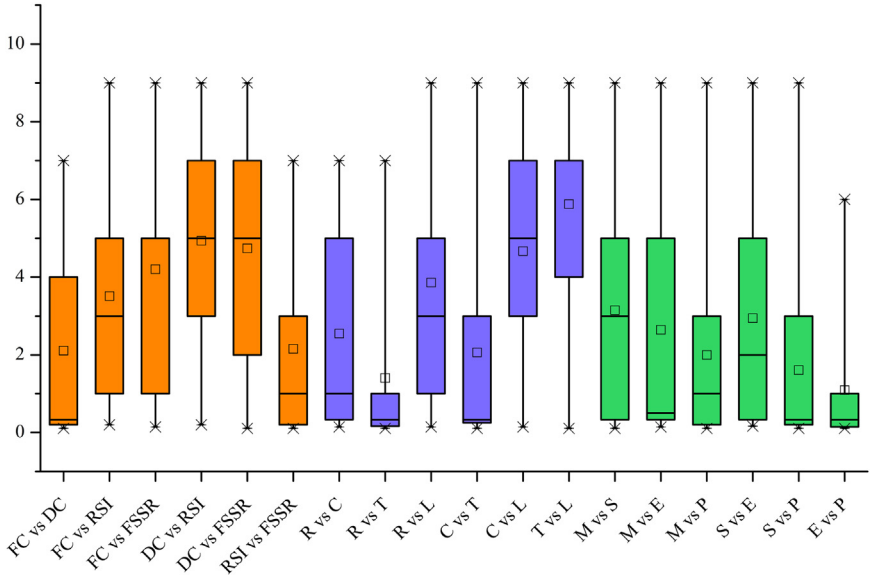

Fig. 1. Summary statistics of experts' assessments. The colored boxes cover the interquartile distance, the black bars inside the boxes represent the medians, the edges of the boxes represent the 25th and 75th percentiles and the whiskers represent the 5th and 95th percentiles of the distributions. Notes: FC- Factor conditions; DC: Demand conditions; RSI: Related and supporting industries; FSSR- Firm strategy, structure, and rivalry; R-Resource; C-Capital; T-Technology; L- Labor; M- Market scale; S-Substitution costs; E-Environmental pressure; P-Policy incentive; A- Attractiveness of investment in related industries; F- Firms' competitiveness.

Table 2
Description of indicators and sources of data.

Indicator	Description	Data sources
Renewable energy resource	Renewable energy resource is the most common indicator to measure resource endowment, reflecting a country's potential for utilizing resources.	[37]
Investment	As a capital-intensive industry, capital support is essential for renewable energy. The duration of investment is from 2010 to 2013. More investment equals faster industry expansion.	[38]
Cleantech innovation	The overall score of cleantech innovation is based on the average between inputs and outputs of clean technology innovation. The higher the score, the stronger the innovation capacity.	[22]
Employees	Labor force is the fount of wealth. This study chooses to measure the labor force by using the number of employees in the renewable energy industry of each country. The larger the number of employees, the larger is the industrial scale.	[39]
Electricity installed capacity	The scale of economies is a key dimension of the renewable energy industry. This study takes electricity installed capacity as the indicator. The larger the installed capacity, the larger the market scale.	[40]
Gasoline price	Gasoline price is the most accessible indicator of fossil energy price in different countries. The higher the gasoline price, the more possibility for fossil fuel substitution by renewable energy.	[41]
Carbon deficit	This study combines the carbon footprint with the Planetary Boundaries framework and carries out precise examination of G20's annual GHG emissions and carbon emission allowance before 2050 on the basis of targets specified in recent assessment reports released by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations (UN). The higher the carbon deficit, the higher is the international pressure in developing renewable energy.	[42,43]
Key investment incentives	Key investment incentives aim to develop a carbon cap, a carbon market, a renewable energy standard, clean energy tax incentives, auto efficiency standards, feed-in tariffs, and government procurement of green bonds. The wider the coverage of investment incentives, the higher is the priority of the renewable energy development.	[44]
Renewable energy country attractiveness index	RECAI is based on the performance of macro stability, prioritization of renewables, bankability of renewables, and project attractiveness in different countries. The higher the score, the more attractive is the industry to investors.	[23]
New and Renewable Global 500 Enterprises	Enterprises play an important role in industrial competitiveness of renewable energy. The more top 500 companies in the new and renewable energy industry, the stronger is the competitiveness of the country.	[45]

price, carbon deficit, key investment incentives, RECAI, and new and renewable global 500 enterprises, as presented in Table 2.

4.2.1. Renewable energy resource

Renewable energy resource is a common indicator for measuring natural resource endowments. According to data for the world's renewable energy resources, provided by the Global Energy Network Institute, and data for territorial area and forestry coverage rate, provided by WB, the renewable energy resource of G20 is divided into 3 levels: A (high), B (middle), and C (low) with 3, 2, 1 in a semi-quantitative way.

4.2.2. Investment

Bloomberg New Energy Finance (BNEF) has made notable contributions to the information on clean energy since 2004. It tracks the transactions across the spectrum of renewable energy finance, from R& D funding and venture capital to public market and asset financing by regions. For this reason, this study chooses to make use of investment data derived from the Pew Charitable Trusts' periodical reports "Who's Winning the Clean Energy Race?", which have tracked the trends in clean energy investment of G20 from 2010 to 2013, the data source for which is BNEF.

4.2.3. Cleantech innovation

The GCII, proposed by Cleantech Group, a company that supports clean technical development and marketability worldwide, is an integrative index that is calculated based on the average between inputs and outputs of clean technology innovation in the G20 nations. By definition, "inputs" denote the development of technology supply, and "outputs" correspond to the creation of market demand.

4.2.4. Employees

There are remarkably large differences among nations with respect to the proportion of employees to a nation's population. Thus, the number of employees in the renewable energy industry has been chosen, rather than the number of total labor. The data come from research reports released by IRENA. The IRENA database includes both direct employment that is generated by core renewable energy activities and indirect employment in upstream industries that supply and support the core activities of renewable energy deployment.

4.2.5. Electricity installed capacity

Electricity from renewable sources could either substitute or complement the electricity generated from fossil fuel. The larger the total installed capacity of a nation, the more likely that demand for renewable electricity in certain conditions will increase. The US Energy Information Administration (EIA) provides data about electricity installed capacity of these countries. It should be noted that EIA's database is not very up to date.

4.2.6. Gasoline price

There is a substitution effect between renewable energy and fossil fuels. If fossil fuels are more expensive than renewable energy, consumers are likely to choose renewables. The gasoline price is the most accessible indicator to measure the price of fossil fuels. In most cases, the higher the gasoline price, the greater the possibility that renewable energy will replace fossil fuels. The EU and Japan, which have cleaner and more efficient energy systems, are good examples. Globalpetrolprices.com provides detailed data about gasoline prices for different countries.

4.2.7. Carbon deficit

There has been a focus on carbon deficit in the context of climate change [42,43], with the aim of assisting policy makers in better understanding not only the gap between current carbon emissions and sustainable development goals (SDGs) but also the need for climatic mitigation strategies, such as reducing greenhouse gases (GHGs), improving the carbon trading market, and levying carbon tax. Based on a series of results attained from previous theoretical innovation, this study not only accounts for annual GHG emissions of the G20 countries, but estimates carbon emission allowance before 2050 by comparison with policy targets that are based on the Fifth IPCC, the Paris Agreement, and SDGs by the UN. Therefore, this article chooses to use the indicator of carbon deficit to quantify the environmental pressure of nations resulting from GHG emissions.

4.2.8. Key investment incentives

Key investment incentives in this study describe policy actions aimed at a carbon cap, a carbon market, a renewable energy standard, clean energy tax incentives, auto efficiency standards, feed-in tariffs, and government procurement of green bonds. The periodical reports

"Who's Winning the Clean Energy Race?", published by Pew Charitable Trust, provide the basis data for crucial investment incentives in G20 countries. There are also numerous investment incentives for conventional energy sources, but these are beyond the scope of this paper.

4.2.9. Renewable energy country attractiveness index

To evaluate the performance of the investment environment for the renewable energy industry in different countries, RECAI has been used to quantify the composite score across macro stability, investment climate, prioritization of renewables, bankability of renewables, and project attractiveness. Note that some countries can be highly attractive for investment in renewable energy, while others might pose barriers to entry [23].

4.2.10. New and renewable global 500 enterprises

In contrast to the oil and gas industry, the renewable energy industry mostly comprises small and medium enterprises that feature sufficient competition and fast technological upgrading. To measure the extent to which different stakeholders compete within the renewable energy industry, this study takes advantage of the "2014 Global 500 Enterprises in New and Renewable Energy," a joint publication by the China Energy News and the China Institute of Energy Economics Research, for quantification. The renewable energy companies from worldwide have been documented by the annual report "Global 500 Enterprises in New and Renewable Energy" since 2011.

4.3. Weighting

4.3.1. Approaches to weighting

As there are obvious differences in the contributions of relevant subfactors to the CIREC, this study distinguishes the importance of indicators by a combination of the Delphi Method with the AHP, which takes the allocation of weighting as a decision-making process. To ensure that the weightings of indicators are reasonable and accurate, we determine the weighting factors for indicators from the first to the second, hierarchically.

4.3.2. Determination of weighting factors

- Step 1: Build a hierarchical structure and an analytic hierarchy model.

Evaluation of renewable energy development requires not only detailed and in-depth theoretical analysis but also a scientifically robust and rigorous framework. To that end, this article applies the AHP to the indicator system of renewable energy competitiveness to establish an analytic hierarchy model, as illustrated in Fig. 2.

- Step 2: Construct a judgment matrix and assign weighting factors.

This study adopts the AHP software for indicator modeling, designs questionnaires, and asks for expert opinions with the Delphi method to assign weighting factors for the first and second level indicators within the interval of 1–9.

- Step 3: Check consistency and calculate the composite indicator.

Weighting factors for each level of indicators are shown in Table 3.

5. Analysis of the G20's renewable energy competitiveness index

5.1. Ranking of G20's renewable energy competitiveness

The minimum–maximum (min–max) method has been adopted to normalize the calculation results of the second-level indicators. Together with the calculation of the indicators at the first and second levels, Tables 4 and 5 show the scores and ranking of G20's renewable energy industrial competitiveness. China and the USA are found to be highly competitive, on the whole, whereas there is a large gap between them and Germany—the third in rank. Apart from Germany, the United Kingdom (UK) and Denmark are two EU countries with strong competitiveness. These are followed by Canada, which performs well in terms of land area and natural endowments. As an emerging economy, Brazil also displays relatively high competitiveness in renewable energy. By contrast, the CIRECs of Indonesia, Saudi Arabia, Russia, Argentina, and Turkey are low, indicating their disadvantages in the renewable energy industry.

5.2. Comparison of the G20's CIREC

5.2.1. Factors of production

The factors of production comprise resource, capital, technology, and labor force.

5.2.1.1. Resource factor. To quantify the resource conditions of renewable energy in the G20 countries, the availability of renewable energy resources has been classified into two levels. According to the calculation, China, the USA, Canada, Australia, Brazil, and Russia belong to the high level, with abundant renewable energy resources. These countries have vast territory, with a great variety of natural resources, revealing inborn comparative advantages. Argentina, India, Indonesia, Mexico, Spain, Turkey, South Africa, and Saudi Arabia belong to the middle level, in which the quantity of renewable energy resources is intermediate. Denmark, France, Germany, Italy, Japan, and the Republic of Korea are classified into the low level, due to the lack of competitive advantage in renewable energy resources.

5.2.1.2. Capital factor. During 2010–2013, China led the world in attracting asset finance, with 219.4 billion USD in the clean energy sector. In 2012, China's investment surpassed the USA by 30billion USD. This has helped China to become the world's leading producer of solar modules and wind turbines. The USA has established itself as a world leader in public and private investments in research and development, maintaining a dynamic hub of renewable energy activity in terms of early stage technology innovation.

Germany ranks third, with a 104.7 billion USD investment over the past four years, followed by Italy, Japan, and Mexico. For each country, the four-year investment is above 50 billion USD [44]. These figures suggest strong capital support for the renewable energy industry in China, the USA, Germany, Italy, and Japan.

5.2.1.3. Technology factor. The USA has the highest competitiveness, in terms of renewable energy technology, among the G20 countries. Denmark ranks second, with excellent performance in the commercialization of clean energy technology. The UK, Canada, and Germany are similar in scores, with a high ability in technology innovation. China falls behind these developed countries in terms of technological competitiveness, ranking in the middle, with a score lower than those of Japan, Korea, and France. The rest of the G20 nations are in the lower ranks.

5.2.1.4. Labor force factor. The number of employees in China's renewable energy sector is estimated to be 2.5 million, accounting for more than 30% of the total employees in this sector globally. The substantial labor force benefits from constant industrial expansion of solar energy and wind energy in China. The number of employees in Brazil's renewable energy sector ranks second in the G20, with an estimated figure of almost 0.9 million. The performances of the USA, India, Germany, and France are also satisfactory in respect of this factor. By comparison, the number of employees in Turkey, Saudi Arabia, Russia, and Mexico is less than 10 thousand, which is too small to be credited.

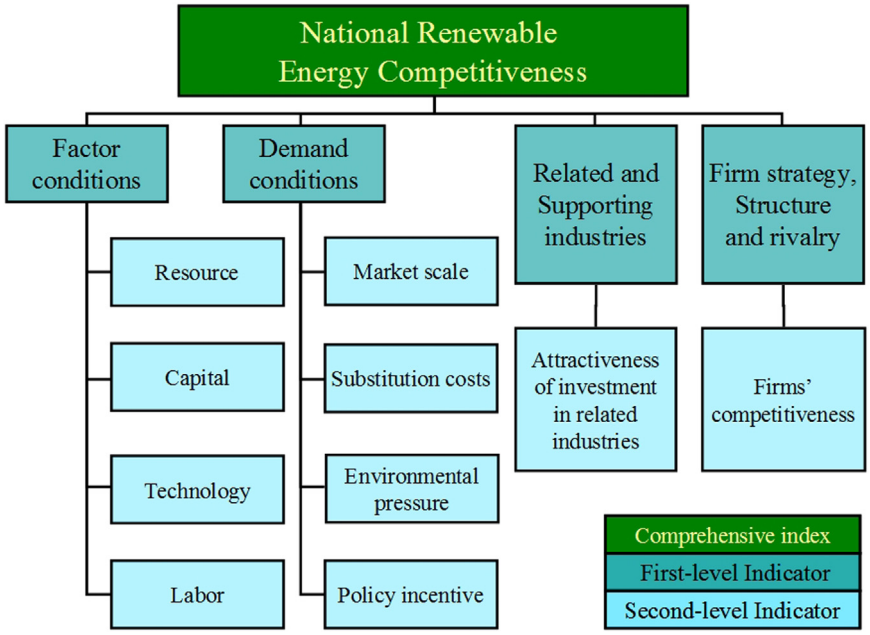

Fig. 2. An analytic hierarchy model of the renewable energy competitiveness indicator system.

Table 3
Weighting for each level of indicators.

First-level indicator	Second-level indicator	Weight
Factor conditions	Resource (R)	0.0777
	Capital (C)	0.0953
	Technology (T)	0.1306
	Labor (L)	0.0266
Demand conditions	Market scale (M)	0.1029
	Substitution costs (S)	0.1004
	Environmental pressure (E)	0.0726
	Policy incentive (P)	0.1238
Related and supporting industries	Attractiveness of investment in related industries (A)	0.1333
Firm strategy, structure, and rivalry	Firms' competitiveness (F)	0.1368

Table 5
Composite index of renewable energy competitiveness (CIREC) for the G20.

Country	CIREC	Ranking	Country	CIREC	Ranking
China	0.8195	1	Italy	0.3480	12
USA	0.7914	2	India	0.3479	13
Germany	0.4881	3	Spain	0.2944	14
UK	0.4465	4	Mexico	0.2529	15
Denmark	0.4319	5	South Africa	0.2167	16
Canada	0.4172	6	Turkey	0.2153	17
Japan	0.3934	7	Argentina	0.1944	18
France	0.3893	8	Russia	0.1515	19
Brazil	0.3879	9	Saudi Arabia	0.1251	20
Australia	0.3652	10	Indonesia	0.0991	21
Republic of Korea	0.3596	11			

Table 4
Standardized scores of the indicators for the G20.

Nation	R	C	T	L	M	S	E	P	A	F
Argentina	0.5000	0.0000	0.1713	0.0106	0.0181	0.7848	0.0261	0.4000	0.0000	0.0061
Australia	1.0000	0.0746	0.3951	0.0155	0.0422	0.5443	0.7015	0.4000	0.4479	0.0675
Brazil	1.0000	0.1044	0.3427	0.3380	0.0931	0.5823	0.0858	0.8000	0.4676	0.0798
Canada	1.0000	0.0952	0.7063	0.0121	0.1043	0.4937	0.6642	0.4000	0.5549	0.0429
China	1.0000	1.0000	0.4825	1.0000	1.0000	0.5633	0.0485	1.0000	1.0000	1.0000
Denmark	0.0000	0.0051	0.9231	0.0205	0.0000	1.0000	0.5000	1.0000	0.3296	0.0429
France	0.0000	0.0686	0.5490	0.0690	0.0991	0.8671	0.4216	0.8000	0.5296	0.0859
Germany	0.0000	0.4747	0.6888	0.1398	0.1405	0.8544	0.4963	0.6000	0.7380	0.2945
India	0.5000	0.1186	0.3986	0.1478	0.2078	0.5570	0.0000	0.6000	0.6197	0.0552
Indonesia	0.5000	0.0009	0.1329	0.0030	0.0293	0.3291	0.0037	0.0000	0.0479	0.0000
Italy	0.0000	0.2705	0.2552	0.0379	0.0948	1.0000	0.3694	0.8000	0.3324	0.0552
Japan	0.0000	0.2558	0.5769	0.0193	0.2405	0.6013	0.4478	0.4000	0.6873	0.2515
Mexico	0.5000	0.2319	0.1189	0.0000	0.0414	0.5063	0.1418	0.6000	0.2761	0.0000
Russia	1.0000	0.0000	0.0000	0.0000	0.1897	0.3165	0.3097	0.0000	0.0000	0.0000
Saudi Arabia	0.5000	0.0000	0.1573	0.0000	0.0345	0.0000	0.6642	0.0000	0.1042	0.0000
South Africa	0.5000	0.0421	0.1958	0.0099	0.0267	0.5886	0.1567	0.2000	0.3690	0.0061
Republic of Korea	0.0000	0.0062	0.5734	0.0049	0.0690	0.7722	0.2761	0.8000	0.4197	0.1779
Spain	0.5000	0.0714	0.3112	0.0424	0.0784	0.7722	0.3396	0.4000	0.2535	0.0982
Turkey	0.5000	0.0112	0.1783	0.0000	0.0371	0.9747	0.1045	0.0000	0.3211	0.0000
UK	0.0000	0.1475	0.7098	0.0239	0.0690	0.9684	0.5075	1.0000	0.5183	0.0368
USA	1.0000	0.7022	1.0000	0.2361	0.9043	0.3354	1.0000	1.0000	0.9352	0.4540

Notes: Resource (R), Capital (C), Technology (T), Labor (L), Market scale (M), Substitution costs (S), Environmental pressure (E), Policy incentive (P), Attractiveness of investment in related industries (A), and Firms' competitiveness (F).

5.2.2. Demand conditions

The demand conditions include market scale, substitution effect, environmental pressure, and incentive policies.

5.2.2.1. Market scale. With respect to the G20's installed electricity capacity, the top two countries are China and the USA. The difference between them is insignificant, estimated at merely 111 GW. Nevertheless, Japan ranks third, with only 27% of China's capacity. Installed electricity capacity in both India and Russia is over 200 GW, which is slightly less than in Japan. Germany surpasses Canada and ranks sixth. Despite its vast territory, Australia ranks behind France, Italy, Brazil, and Spain, perhaps due to its unique population distribution and industrial structure. It is worth noting that Denmark, which has the least electricity installed capacity in the G20 member countries, ranks fifth in competitiveness of renewable energy. Clearly, Denmark's performance is satisfactory in many other respects, offsetting the undesirable performance of its electricity installed capacity.

5.2.2.2. Substitution effect. The retail prices of gasoline in Denmark, Italy, Germany, France, the UK, Turkey, and Spain are notably high; consequently, renewable energy in these countries experiences a significant substitution effect. Saudi Arabia and Russia, which both profit from abundant domestic oil and gas resources, have quite low retail oil prices and, therefore, small demand for substituting renewable energy for fossil energy. China and the USA, which have oil retail prices that are above and below the world-average, respectively, are two major manufacturers of goods. Likewise, the substitution effect in China would be stronger than is that in the USA.

5.2.2.3. Environmental pressure. The Paris Agreement, which was reached recently, proposes a long-term goal of keeping the increase in global average temperature to within 2 °C. To that end, the next step would be the allocation of rights for greenhouse gas (GHG) emissions to the national level based on the current population (i.e., on a per capita basis). It is unsurprising that, once a nation's GHG emissions exceed the maximum sustainable level, there will be a carbon deficit that will create environmental pressure. In other words, the country would be in urgent need of energy saving and emission reduction measures. Our assessment shows that the USA has the highest carbon deficit per capita and, thus, is exerting great pressure on the environment. The USA is followed by Australia, Saudi Arabia, Canada, the UK, Denmark, Germany, and France, all of which are developed countries that are contributing most to global warming associated with human activities. By contrast, developing countries, such as India, Indonesia, and China, have rather low emissions that are disproportional to their huge population.

5.2.2.4. Incentive policies. Most G20 countries have promulgated incentive policies to promote the renewable energy industry. According to statistics on relevant policies across the world, China, the USA, the UK, and Denmark rank top in terms of the number of implemented policies over a broad spectrum. These include renewable energy standards, tax incentives, and feed-in tariffs. France, Italy, the Republic of Korea, and Brazil follow behind, and Germany, India, and Mexico come last. Lower-ranking countries include Indonesia, Turkey, Russia, and Saudi Arabia, who all have weak policy incentives in the renewable energy industry and lack clear and continuous policy actions.

5.2.3. Related industries and supporting industries

Through comparison of investment attractiveness indicators among the G20 countries, the investment environment in the renewable energy industry in China, the USA, and Germany is seen to be healthier China is a major manufacturer of renewable energy equipment worldwide. In PV power generation equipment, for instance, China has produced most of the PV devices consumed in the world. By comparison, related industries and supporting industries are lacking in Russia, Argentina, and Indonesia; this has been an obstacle to attracting investment.

5.2.4. Competitiveness of enterprises

China accounts for 163 state-owned and non-state enterprises among the top 500 in the new and renewable energy industry; this figure is larger than that in the USA, which ranks second in the world. In recent years, with the expansion of renewable energy manufacturing and power generation, numerous Chinese enterprises have emerged both upstream and downstream of the renewable energy industry. Currently, both the number of Chinese enterprises in the top 500 and the gross revenue are on the rise. The USA and Germany's enterprises are also competitive—these countries have three and two enterprises among the world's top 10, respectively. No enterprises in Indonesia, Mexico, Russia, Saudi Arabia, and Turkey are in the top 500 list, suggesting relatively weak competitiveness in the renewable energy industry.

5.3. Analysis of the competitiveness of five representative countries

To provide a concrete example of how industrial competitiveness of renewable energy affects national performance, five representative countries have been selected for in-depth investigation. The results indicate that there are significant differences in the development and utilization of renewable energy among nations, even though every country investigated has made great efforts to develop its domestic renewable energy industry.

5.3.1. China

As previously stated, China's performance in the renewable energy industry is prominent. Its competitiveness ranks first among the G20 countries. Specifically, China ranks top in factors of resources, capital, labor, market scale, policy incentive, attractiveness of investment in related industries, and firms' competitiveness, whereas technology and substitution costs are the restricted factors for China (Fig. 3).

China has been implementing renewable energy development for only a few years. The development of renewable energy policies can be

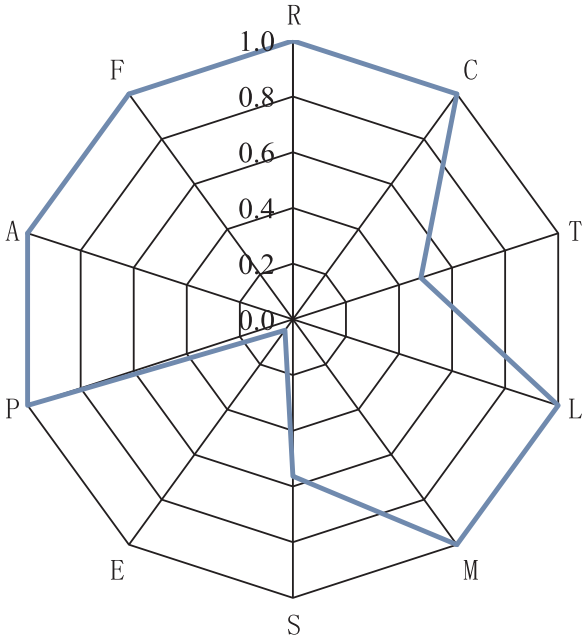

Fig. 3. Each index score in China. **Notes:** Resource (R), Capital (C), Technology (T), Labor (L), Market scale (M), Substitution costs (S), Environmental pressure (E), Policy incentive (P), Attractiveness of investment in related industries (A), and Firms' competitiveness (F). The same applies below.

traced back to 2005, when the Renewable Energy Law of the People's Republic of China was adopted. In 2010, renewable energy was identified as an emerging strategic industry in China's 12th Five Year Plan. Driven by the country's ambitious goal to become a net exporter of renewable energy, the investment in these sectors in China surged from 5.8 billion USD in 2005 to 54.2 billion USD in 2013, allowing for the highest financial support globally. This has resulted in massive economies of scale on a renewable manufacturing base. Currently, China ranks first in terms of installed capacity of wind power and solar PV.

China has taken the leading role in the industrial chain of the world's renewable energy. In 2014, China's output of poly silicon, battery chips, solar panels, and silicon slices accounted for 43% 59%, 70%, and more than 75%, respectively, of the global market share. The huge scale of production scale drives reduction in cost. For example, the cost of China's solar panels in the third quarter of 2014 was only 40% of that in the fourth quarter of 2010 [46].

The Chinese government attaches great importance to renewable energy development, and has been constantly upgrading its planning objectives. The “Medium and Long-Term Development Planning of Renewable Energy,” issued in 2007, proclaimed that the national installed capacity of hydropower, wind power, and solar power shall reach 300 GW, 30 GW, and 1.8 GW, respectively, by 2020 [47]. Five years later, Chinese National Energy Administration (NEA) updated these development goals by increasing them to 290 GW, 100 GW, and 21 GW, respectively, by 2015 in the “Twelfth Five-Year Plan” [48]. In addition, the Law of Renewable Energy, issued in 2005, which asked grid companies for the full purchase of renewable electricity, was revised in 2009 by establishing the indemnificatory purchase principle. All these measures have tremendously promoted the development of China's renewable energy industry [49].

5.3.2. The USA

The USA ranks second among the G20 countries in terms of industrial competitiveness of renewable energy. Its sound competitiveness benefits from advanced energy technology, abundant resources, huge market scale, and environmental pressure (Fig. 4).

Because of the government's policy incentives and flexibility of commercial modes, the USA plays a leading role in renewable energy technology, which is a major driver of renewable energy competition. The development and application of advanced technology have facilitated upgrading grid-connection and energy storage.

The USA has enacted a series of strategies, planning, and policies in recent years in the field of renewable energy; these include tax credit, a carbon market, renewable energy standard, and net metering. Tax credits, which allow renewable power projects to be subsidized, has been found to be the most influential policy launched by the Energy Policy Act of 1992. Subsequently, the USA formally adopted the policy of Investment Tax Credit, offering a tax credit of 30% of investment [50].

In addition, the USA has created a variety of innovations in business modes for renewable power generation; these include Solar Lease, by Solarcity; Power Purchase Agreement (PPA); and yieldco. Investors, users, owners, and other stakeholders are effectively interconnected through a fund flow, thereby increasing the ability to overcome financing problems in the renewable energy industry.

5.3.3. Germany

Germany ranks third in the industrial competitiveness of renewable energy. It has excellent performance in terms of support from related industries, advanced technology, policy mechanism, and, particularly, mechanism design, which serves as a driving force for related industries and technological progress (Fig. 5).

Power generation by renewable energy in Germany increased from 18.9 billion KW h in 1990 to 156 billion KW h in 2014, representing 25.8% of the national generating capacity. The steady development of the German renewable energy industry is supported by the Renewable Energy Sources Act (EEG). The act came into operation in 2000, with the aim of building fixed feed-in tariffs of power generated from renewable energy, requiring the power grid to prioritize the connection of renewable electricity, and providing a desirable investment environment for renewable power projects. The EEG has been revised several times. In the 2014 revision, the market mechanism was introduced to renewable energy projects, meaning that the funding rates of renewable electricity will no longer be set by the government but will, rather, be determined by auction [51].

The steady development of the renewable energy industry in Germany also benefits from the flexibility of the electricity system, which links power generation with consumer markets efficiently. Germany has made constant efforts to eliminate the lack of conformity between the load center and the resource area arising from long-

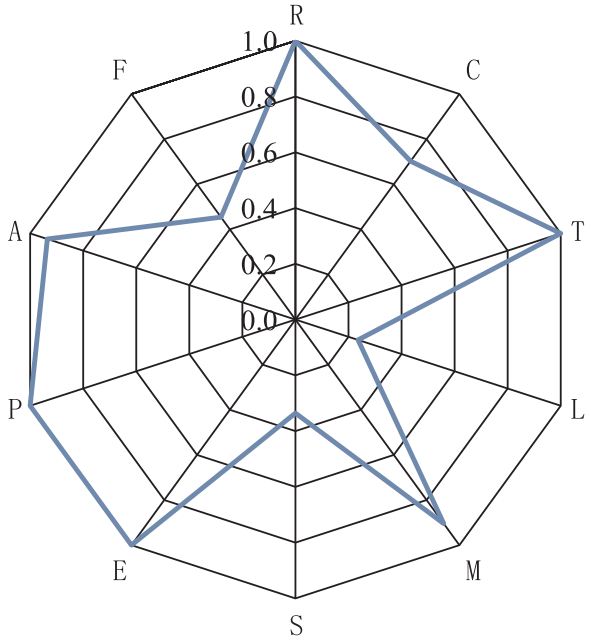

Fig. 4. Each index score in the USA.

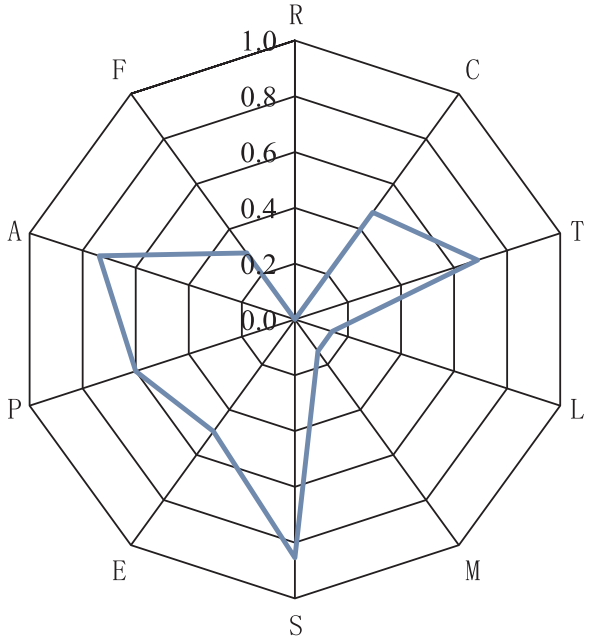

Fig. 5. Each index score in Germany.

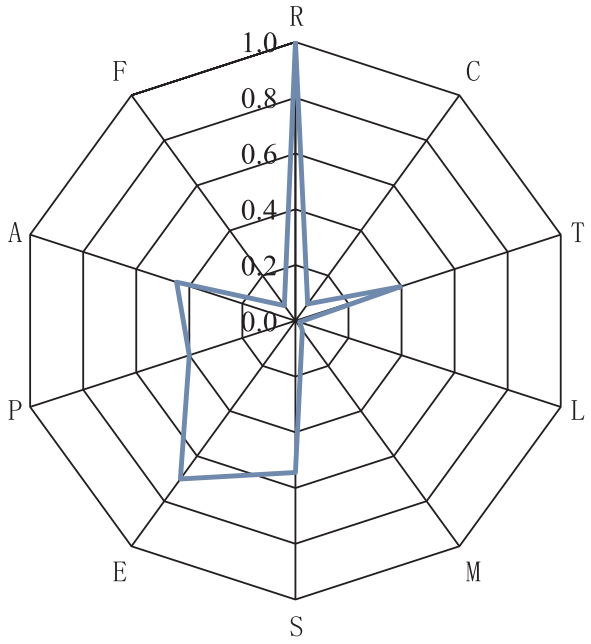

Fig. 6. Each index score in Australia.

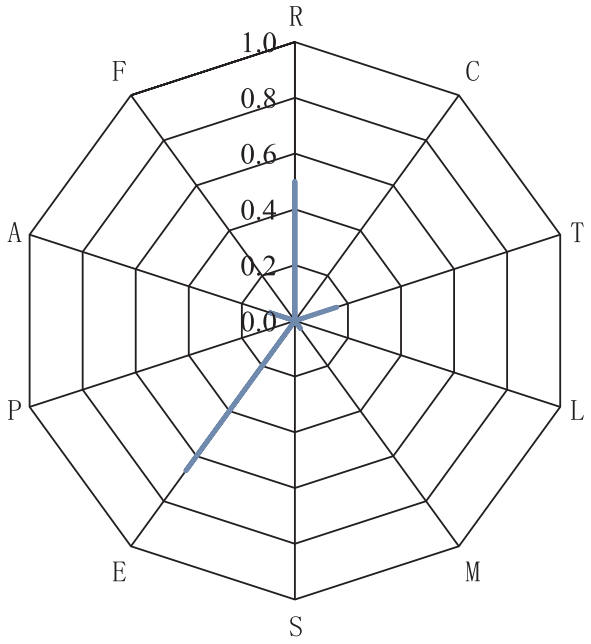

Fig. 7. Each index score in Saudi Arabia.

distance transmission. As a major member of the EU, Germany's interconnection with other European grids may increase system resilience and facilitate higher penetrations of intermittent renewable electricity [52].

5.3.4. Australia

Australia ranks tenth in renewable energy competitiveness among G20 countries, but it serves as a nice example of how policy could affect renewable energy. The country's fairly good performance benefits from abundant renewable energy resources, well-developed technology and related industries, and quite high substitute costs (Fig. 6). Australia is rich in solar and wind energy resources, making it one of the most suitable countries for establishing renewable power stations in large parts of the country. With a total installed capacity of 2500 MW, Australia ranks fifth globally in terms of renewable energy installed capacity per capita (excluding hydropower).

Australia began to develop renewable energy in the early 2000s. In 2001, the Australian government sought to raise the contribution of renewable energy sources in the electricity mix by 9500 GWh per year [53]. In 2009, a new national plan was formulated, raising the mandatory target of renewable energy by 2020 from 9500 GWh to 45,000 GW h. Unfortunately, it has been altered by the Conservative Government, which remains neutral to all types of energy, rather than giving priority to renewable energy [54], implying a conservative position on embracing renewable energy. As a result, in 2014, investment in wind power, solar power, and other renewables in Australia reduced by 88%, compared with 2013, dropping from 2 billion AUD to 0.24 billion, touching the floor since 2002.

5.3.5. Saudi Arabia

Saudi Arabia is a typical country facing the problem of the resource curse among G20 countries. The country's substantial fossil fuel subsidies weaken the competitiveness of the renewable energy industry. Despite its natural endowment of solar energy, Saudi Arabia has achieved nothing remarkable in renewable energy competitiveness (Fig. 7). As over 60% of the electricity load comes from refrigeration of air-conditioning, the peak of electricity consumption occurs when solar PV power generation has the highest output. This is partly why Saudi Arabia has paid attention to exploiting solar energy. According to the King Abdullah City for Atomic and Renewable Energy, Saudi Arabia plans to expand the installed capacity of solar by 41 GW, and that of wind energy by 9 GW, within 20 years.

In striving to turn the blueprint of renewable energy development into reality, Saudi Arabia still needs to remove multiple obstacles, one of which is the substantial fuel subsidies. In early April 2015, Saudi Arabia's retail gasoline price was only 0.16 USD/L, much lower than that of Russia (0.66 USD/L). Furthermore, the slump in oil prices since 2014 may undermine the economic competitiveness of renewable energy, due to reducing substitute costs, and compromise the country's motivation for developing the renewable energy industry.

6. Discussions and policy recommendations

6.1. Discussions

In previous studies, researchers have come up with multiple indicator systems of competitiveness ranking. These studies are primarily based on the comparative advantage theory, which generally lacks systematic and comprehensive analysis. Other systematic comparisons, such as Ernst & Young's RECAI, and Cleantech Group's Global Cleantech Innovation Index, do not focus exclusively on the evaluation of renewable energy industry or theoretical underpinning remains questionable.

Consequently, this paper has chosen to employ the Diamond Model to provide an overall picture of the industrial competitive advantage of the G20 that conveys valuable information to decision makers in both governments and enterprises. In this sense, the study somehow bridges the gap between academics, who neglect practical knowledge, and industrialists, who lack scientific underpinning.

By establishing a sound and unified framework for renewable energy competitiveness, this paper manages to create combined effects of the longitudinal analysis that covers the factors along the industrial chain and the transverse analysis that covers the external factors influencing the renewable energy industry [55]. In doing so, renewable energy competitiveness can be attributed to factor conditions, demand conditions, related and supporting industries, and firm strategy, structure, and rivalry. These four factors are then decomposed into ten sub-indicators: resource, capital, technology, labor, market scale, substitute costs, environmental pressure, policy incentive, attractiveness of investment in related industries, and enterprises' competitiveness. The

resulting indictor system proposed in our article not only gives full consideration to complexity and variation of national renewable energy industry but also takes data availability and reliability into account. The original data sources are either collected from governmental and organizational reports or calculated based on reasoned modeling that has been validated by the scientific community.

It is undeniable that our analysis has limitations and controversy. For example, not all the data sources derived for accounting for a variety of indicators are on the same timeline. The availability and reliability of data prevents us from selecting some indicators that are highly representative. Nevertheless, with more data accessibility for countries like Russia, more scientifically robust indicators can be included in accounting for the CIREC in the future. Moreover, carbon deficit is presented in relative terms (per capita) rather than in absolute terms (total emissions), which somehow appears inconsistent with other indicators. This is because equity is fundamental in climate change policy research, for which a globally comparable per capita basis would be the best option, but also due to the fact that looking at the total amount of China's carbon emissions would result in a higher score of CIREC, which is at odds with the reality. Last, but not least, as the national performance is evaluated essentially from an integral perspective, rather than from a per capita perspective, the final results seem more favorable to China, the USA, and some other big countries, thus bringing the risk of underestimating the progress that small countries have made.

6.2. Policy recommendations

According to our assessment, a country's sustainable development of renewable energy depends largely on the formulation and implementation of a set of well-designed renewable energy policies by the government. In addition to this, international experience and collaboration make sense. For example, if one country's power grid has connections with neighboring countries, its renewable energy industry is likely to be competitive. To help countries improve the industrial competitiveness of renewable energy, recommendations can be made to help governments take policy initiatives, as follows.

6.2.1. Establishing strategic priority for renewable energy development

As indicated in the G20's competitiveness ranking list, developing countries stand almost on the same starting line with developed countries. Many countries face similar challenges in this field; one of these challenges is the lack of adequate financial subsidies. For this reason, it is suggested that governments take renewable energy as a priority in national energy strategies. One example of this is China, which has supported renewable energy projects by providing financial subsidies since the Renewable Energy Law came into force [56,57]. The renewable law provides a legal basis for supporting renewable electricity generation. As the development of renewable energy relies on the power grid, energy storage, and many supporting facilities, governments may set up regulatory agencies in charge of the planning, regulation, coordination, and supervision of issues in relation to renewable energy. Many countries, such as the USA and India, have been doing so to strengthen their role in promoting renewable energy industries. This may provide solutions to the difficulties, such as poor grid connection.

6.2.2. Maintaining the stability and consistency of renewable energy policies

Practical renewable energy policies cannot be undertaken without a well-designed energy strategy determined by a country's regulation, system, market environment, technological advance, amid other factors. At the same time, continuous stability of incentive mechanisms could guarantee the benefit of investment by sparking entrepreneurs' enthusiasm. One example is the USA, the state governments of which stabilize market expectation with quotas, while the federal government provides indirect supporting policies, such as financial and tax incentives. Because of the urgent need for reduction in GHG emissions and energy import, Germany ensures investors' returns through a stable, long-term feed-in tariff policy, directly encouraging the development of renewable energy. In contrast, Australia has experienced a striking transition of renewable energy policy between the Conservative Government and the Liberal Government. These examples demonstrate that a policy of stability and consistency is an important prerequisite for the sustainable development of the renewable energy industry.

6.2.3. Improving electricity grid stability to accommodate ever-growing renewable energy

Improving electricity grid stability is a vital element in the struggle to take advantage of the growing volumes of intermittent generation of renewable electricity. Much can be learned from the large-scale integration of solar and wind energy in the grid of Germany and Denmark. The benefits of strengthening the electricity grid in EU member states could be assessed in terms of economics, energy security, and renewable energy goals. By comparison, the inability to accommodate surplus electricity in remote areas is becoming a major impediment to renewable energy development in China. The Chinese government must maintain its restrictions on new wind farms in northwest China, where grid infrastructure is rather weak. As renewable energy penetration rates increase, smart grid technology could be provided to improve grid resilience and reliability.

7. Conclusions

This article presents a systematic and in-depth analysis of the G20's renewable energy industry competitiveness and main driving factors. The conclusions drawn are as follows:

(1) The revised Diamond Model presented in this paper is appropriate for use in comparing the resource, economic, industrial and regulatory aspects of renewable energy competitiveness of nations in a general sense.
(2) There are significant differences between the G20 countries' performances in renewable energy competitiveness. Highly competitive countries include China, the USA, Germany, the UK, and Denmark; weakly competitive countries include Indonesia, Saudi Arabia, Russia, Argentina, and Turkey, and the competitiveness of the other countries is intermediate.
(3) Factors affecting national renewable energy competitiveness are complex and varying. As there is no universally valid development mode, countries shall both adopt measures that depend on their own national conditions and make full use of their own advantages.
(4) Major countries worldwide are equipped with the basic conditions to develop renewable energy. Improving renewable energy competitiveness is, thus, not dependent mainly on the abundance of resources that one country has but, rather, on the way in which renewable energy develops.
(5) To improve international competitiveness, governments should give priority to the renewable energy industry in their energy development strategies, maintain the stability and consistency of renewable energy policies, and improve electricity grid stability to accommodate ever-growing renewable energy.

We fully acknowledge that there are limitations in aspects of our analysis, such as data collection, indicator selection, and results interpretation. As there is little relevant literature focusing on the G20's renewable energy competitiveness, it seems difficult to validate our results by comparing them with those of existing studies. In addition, national renewable energy competitiveness is a dynamic concept that will evolve over time. Therefore, any definition and interpretation cannot be valid for all purposes. However, there still seems to be room for both improving the underlying theory and methodology and strengthening the scientific robustness of datasets and the indicator

system to provide more useful and timely information for governments and enterprises to make wise decisions.

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